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PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in or relating to Gas Lasers.

5 We, WESTERN ELECTRIC COMPANY, INCORPORATED, of 195 Broadway, New York City, New York State, United States of America, a Corporation organized and existing under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 This invention relates to gas lasers.

15 While it has heretofore been appreciated that gas lasers can provide the stimulated emission of radiation with line widths that are generally narrower than those of solid state lasers, they have produced relatively low output powers on a continuous-wave basis.

20 According to the present invention there is provided a gas laser having as an active medium a mixture of nitrogen, helium, and a gas selected from carbon dioxide and nitrous oxide.

25 Thus, we have discovered that metastable helium provides an efficient means of exciting nitrogen in order to populate the 00⁰1 upper laser state of carbon dioxide. We have found that in order to obtain a high degree of beneficial interaction, wall de-activation of metastable helium should be reduced below a critical level by providing a laser tube having a diameter that is at least two inches and that, even so, the ranges of pressures of helium, nitrogen and the active gas for which the maximum beneficial interaction is obtained are extremely narrow and quite critical. When the tube diameter in the lasing region is at least two inches, preferably the pressure of the active gas lies in the range between 0.2 and 0.4 Torr, the pressure of nitrogen gas lies in the range between 1.0 and 1.5 Torr, and the pressure of the helium lies in the range between 3.0 and 10.0 Torr.

40 The invention will now be described with

reference to the accompanying drawings, in which:

45 FIG. 1 shows schematically and block diagrammatically a partially cutaway view of a preferred embodiment of the invention; and

FIG. 2 shows an energy level diagram that will be useful in explaining the invention.

50 As illustrated in FIG. 1, a laser includes the interaction region comprising a tube 20 having an internal diameter of at least two inches in the portion in which the lasing action was obtained, apparatus for furnishing therein an appropriate gas mixture and apparatus for exciting the gas mixture with a direct current discharge with a sufficiently high voltage to ionize the helium.

60 Illustratively, the gas mixture is furnished by a continuous flow thereof from suitable sources 41, 42 and 43 of carbon dioxide, nitrogen and helium, respectively. The gases flow through mixing regions 32 and inlet apparatus 12 into the interaction region; and the spent gases are removed from the interaction region to the exhaust 40 by a pump 31.

70 The gas mixture is excited by electrical discharge apparatus disposed, for convenience, in one branch of the inlet apparatus 12. Specifically, the discharge apparatus includes the oxide-coated cathodes 14 disposed in bulbous appendages 19 of apparatus 12 near ends of tube 20, the anode 15 disposed in the bulbous appendage 17 of tube 20, the d.c. voltage sources 13 with positive terminals connected to anode 15 through current-limiting resistors 16 and negative terminals connected to cathodes 14, and the heater current sources 22 connected across cathodes 14.

75 To increase the so-called population inversion between the upper and lower laser levels, i.e., the energy states associated with the stimulated radiation, it is desirable to increase the difference between the so-called rotational

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temperature and the vibrational temperature of the carbon dioxide. To this end, the tube 20 is surrounded by the jacket 21 through which was flowed a coolant from source 26 to exhaust 27. Water at 15°C. is used in the experiments described in detail herein but any other coolant capable of depressing the rotational temperature of the gas below room temperature could be used, for example, methanol at -78°C. The coolant determined the wall temperature of the tube 20 and thus depresses the rotational temperature of the carbon dioxide. It appears that the vibrational temperature is not substantially affected by the coolant.

To achieve oscillation, it is important to include the interaction region in an optical resonator. In the specific design being discussed, the resonator is formed by a pair of mirrors 33 and 34, the latter concave with 50 meters radius of curvature and the former convex with 48.5 meters radius of curvature in order to enlarge the mode volume to use the entire gas mixture within the interaction region for laser action. For the best results achieved thus far, energy is coupled out from the resonator through a 15 millimeter diameter aperture in the centre of convex mirror 33. The mirrors are spaced 300 centimeters apart and were supported by suitable mirror mounts 36 and 35, respectively; and they are coated to be opaque with vacuum-deposited gold. The aperture diameter may vary from any lower limit up to 25 millimeters while still obtaining substantially improved results, as compared to previous vibrationally excited gas mixtures.

If the laser be intended for use as a straight-through amplifier, the resonator becomes unnecessary; and the mirrors can be eliminated. In some instances it may be preferred to locate the mirrors outside the interaction region, in which case Brewster-angle windows (for example, of crystalline zinc oxide, barium fluoride or potassium chloride) can be used to confine the interaction region. If the laser be used in the ring laser form, three or more mirrors will be used to form the ring.

Another use for a large diameter laser is as a multipass amplifier. In this case, the mirrors may be disposed to define non-

overlapping paths for the beam in the tube.

The tube 20 in which the multiple gases interact in the embodiment of FIG. 1 is a glass tube, although it could be some other rigid tubular structure, such as a tube of non-conducting plastic or quartz. The glass tube 20 extends the distance between mirrors 33 and 34 and has an inside diameter of 3 inches. The effective interaction region is observed to extend between the points at which apparatus 12 enters tube 20 and was about 2.5 meters long.

Cathodes 14 are oxide-coated cathodes having platinum bases and containing barium carbonate and strontium carbonate in the respective proportions 55% and 45% by weight.

Laser oscillation was obtained at a number of wavelengths involving P-branch rotational transitions P (14) to P (26), primarily P (18), P (20), P (22). The strongest transition corresponding to P (20) occurred at 10.5915 microns.

The laser power output is measured by a calibrated thermopile disposed beyond the aperture of convex mirror 33.

It should be understood that the output stimulated radiation has a variety of uses and that the calibrated thermopile could illustratively be replaced by a desired utilization apparatus 25, which could, for example, be an electro-optic modulator responsive to an information signal. The laser is particularly useful for communication, inasmuch as the atmosphere has relatively low attenuation at 10.6 microns. The wavelength range near 10.6 μ is commonly called an "atmospheric window".

The best specific example of operation obtained thus far involves a mixture in which the carbon dioxide has a pressure of 0.33 Torr, the nitrogen has a pressure of 1.0 Torr and the helium has a pressure of 6.0 Torr. Water flows through jacket 21 at 15° centigrade. Each of sources 13 provides 120 milliamperes of current at 4400 volts, i.e., about 1058 watts of power; a continuous-wave power output of 133 watts from the laser being measured by the calibrated thermopile. The overall efficiency is 12.5 per cent.

Various specific examples of the operation of the laser areas follows, example 8 being that just given:

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75

80

85

90

95

100

Pressure

Total m

Aperture

Coolant

Coolant

Cathode heater p

Pumping

Pumping

Pumping W₁ & W₂Output p W₁ & W₂

Efficiency

It is considered these ob-
5 tion of carbon d-
sition oc-
states of carbon
10 energy s-
level of
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nitrogen
portion o
15 levels of
The
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of the hel
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20 decays
having an
difference
heating of
portant to
metastable
25 from the
lifetime
through the

		Examples							
		1	2	3	4	5	6	7	8
Pressure	CO ₂	Torr	0.5	0.2	0.35	0.4	0.33	0.33	0.33
	N ₂	Torr	2.5	1.0	1.0	1.0	1.00	1.0	1.0
	He	Torr	—	4.67	5.0	3.5	4.00	5.0	6.0
Tot. mixture flow rate		3 litres/sec.							
Aperture dia.	Mms	10mm	10mm	25mm	10mm	10mm	15mm	15mm	15mm
Coolant temp.	°C.	15°C.	15°C.	15°C.	15°C.	15°C.	15°C.	15°C.	15°C.
Coolant flow rate	Gpm.	10 gallons per minute							
Cathode total heater power	Watt	(100 watts each)							
		200 watts							
Pumping v.	v ₁ (volts)	2700	3800	3800	3800	4000	4800	4700	4400
	v ₂ "	2700	3800	2700	4000	3600	3900	4000	4400
Pumping cur.	I ₁ (MA)	87	160	160	180	150	136	130	120
	I ₂ "	87	140	170	170	185	196	150	120
Pumping power									
W ₁ & W ₂	Watts	474	1140	1237	1124	1265	1415	1210	1058
Output power									
W ₁ & W ₂	Watts	15.0	55.0	53.6	82.5	103	116	108	133
Efficiency per cent		3.2	4.8	4.3	7.1	8.2	8.2	9.0	12.5

It is suggested that the following theoretical considerations, account, at least in part, for these observed results. In the left hand portion of FIG. 2, the relevant energy states of carbon dioxide will be found. The laser transition occurs from one of the rotational energy states of the 00⁰1 vibrational energy level of carbon dioxide to one of the rotational energy states of the 10⁰0 vibrational energy level of carbon dioxide. In the central portion of FIG. 2 are shown the energy levels of nitrogen that are of interest. In the right hand portion of FIG. 2, we have shown the energy levels of helium that are of interest.

The voltage of the applied pumping discharge is sufficient to ionize substantially all of the helium. Helium has an ionization potential of 24.6 volts. Nevertheless, ionized helium decays quickly to metastable helium atoms having an energy of 19.8 volts. The energy difference is lost through fluorescence and heating of the gas. At this point, it is important to note that the proportion of the metastable helium that can be kept away from the walls of tube 20 has a relatively long lifetime and can produce atomic nitrogen through the following interaction:



Because the dissociation energy of a nitrogen molecule is exactly half of the energy of a metastable helium atom, this process proceeds with nearly perfect efficiency and results in the spectacular output powers and efficiencies described above. Referring to FIG. 2 again, it will be seen that the atomic nitrogen level at 9.9 volts is substantially above the energy level of the upper laser level in carbon dioxide. Nevertheless, the nitrogen atoms decay in an orderly step-by-step process through higher vibrational levels and then through v=4, v=3, v=2, and v=1 energy levels to the ground state of nitrogen, each time transferring to carbon dioxide molecules exactly that amount of energy needed to excite the 00⁰1 vibrational level, which is the upper laser level. It will be seen in FIG. 2 that the vibrational levels of v=1 through to v=4 are all equally spaced in energy and that the v=1 level is also spaced by a like amount from the nitrogen unexcited ground state, respectively. Vibrational levels v=5 through to about v=40 occur between the v=4 level and the atomic nitrogen level and

involve little energy. The process is surprisingly efficient because only a small amount of the energy of the cascade is wasted. The present invention provides a uniquely efficient means for exciting the atomic nitrogen level at 9.9 volts.

Moreover, if the tubes has an internal diameter greater than about two inches, it appears that an appreciable amount of metastable helium has a lifetime long enough to ionize the nitrogen before colliding with and being de-activated by the tube wall 20. It has also been found that the pressure ratios are critical for optimum beneficial effect of the helium.

One modification of the present invention involves the use of nitrous oxide as the active gas instead of carbon dioxide. Because of the closeness of certain of its energy levels, useful for laser action, to the corresponding energy levels of carbon dioxide, all of the foregoing considerations stated as applicable to carbon dioxide are also applicable to nitrous oxide. Previous laser experiments with both carbon dioxide and nitrous oxide indicate that these gases are sufficiently similar that the useful ranges of working pressures of nitrous oxide in combination with nitrogen and helium would be approximately the same as the corresponding range of pressures of carbon dioxide. Similarly, the useful ranges of pressure for the helium and the nitrogen should be approximately as described above.

Instead of the electric discharge described above, the helium may be energized in a different manner, as by a radio frequency discharge.

WHAT WE CLAIM IS:—

1. A gas laser having as an active medium a mixture of nitrogen, helium and a gas selected from carbon dioxide and nitrous oxide.

2. A laser according to claim 1, in which a container for said active medium has lateral walls spaced at least one inch from a central axis of the container over the region in which lasing action is obtained.

3. A laser according to claim 1 or 2, in which said gas selected from carbon dioxide and nitrous oxide has a pressure between 0.2 and 0.4 Torr, said nitrogen has a pressure between 1.0 and 1.5 Torr, and said helium has a pressure between 3.0 and 10.0 Torr.

4. A laser according to claim 3, in which said active medium comprises carbon dioxide at a pressure of 0.33 Torr, nitrogen at a pressure of 1.0 Torr and helium at a pressure of 6.0 Torr.

5. A laser according to any one of the preceding claims, including an anode and an oxide coated cathode for establishing an electrical discharge through said active medium.

6. A laser according to any one of the preceding claims, including means for cooling said active medium to below room temperature.

7. A laser comprising a cylindrical tube containing a mixture of gases and having an inlet and outlet for said gases, said tube having an inside diameter of at least three inches and having reflective end members, one of said reflective end members being partially transmissive to permit the abstraction of said radiation; means for flowing said mixture continuously through said inlet and outlet; said mixture including carbon dioxide having a pressure between 0.2 and 0.4 Torr, nitrogen having a pressure between 1.0 and 1.5 Torr, and helium having a pressure between 3.0 and 10.0 Torr; a cooling jacket surrounding said tube and apparatus adapted to circulate a coolant through said jacket; and direct-current discharge apparatus comprising an anode disposed with a surface within said tube, an oxide-coated-cathode disposed in the input flow path of said gas mixture, and a direct-current voltage source connected between said anode and said cathode and having a voltage sufficient to ionize said helium in said tube, said apparatus including means for heating said oxide-coated-cathode.

8. A laser according to any one of the preceding claims, including an optical resonator adapted to resonate a vibrational-rotation stimulated transition of said gas selected from carbon-dioxide and nitrous oxide.

9. A gas laser arranged and adapted to operate substantially as herein described with reference to and as shown in the accompanying drawings.

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